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THESIS

AN ANALYSIS OF THE IMPACT OF DATA ERRORS ON BACKORDER RATES IN THE F404 ENGINE SYSTEM

by

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March 2003

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13. ABSTRACT *(maximum 200 words)*

In the management of the U.S. Naval inventory, data quality is of critical importance. Errors in major inventory databases contribute to increased operational costs, reduced revenue, and loss of confidence in the reliability of the supply system. Maintaining error-free databases is not a realistic objective. Data-quality efforts must be prioritized to ensure that limited resources are allocated to achieve the maximum benefit.

This thesis proposes a methodology to assist the Naval Inventory Control Point in the prioritization of its data-quality efforts. By linking data errors to Naval inventory performance metrics, statistical testing is used to identify errors that have the greatest adverse impact on inventory operations. By focusing remediation efforts on errors identified in this manner, the Navy can best use its limited resources devoted to improvement of data quality.

Two inventory performance metrics are considered: Supply Material Availability (SMA), an established metric in Naval inventory management; and Backorder Persistence Metric (BPM), which is developed in the thesis. Backorder persistence measures the duration of time that the ratio of backorders to quarterly demand exceeds a threshold value. Both metrics can be used together to target remediation on reducing shortage costs and improving inventory system performance.

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AN ANALYSIS OF THE IMPACT OF DATA ERRORS ON BACKORDER RATES IN THE F404 ENGINE SYSTEM

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In the management of the U.S. Naval inventory, data quality is of critical importance. Errors in major inventory databases contribute to increased operational costs, reduced revenue, and loss of confidence in the reliability of the supply system. Maintaining error-free databases is not a realistic objective. Data-quality efforts must be prioritized to ensure that limited resources are allocated to achieve the maximum benefit.

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS

BPM	Backorder Persistence Metric
CARES	Computation and Research Evaluation System
DDF	Due-in/Due-out File
DEN	Data Element Number
DIQ	Data/Information Quality
DLA	Defense Logistics Agency
ERP	Enterprise Resource Planning
EOQ	Economic Order Quantity
IHF	Inventory History File
MDF	Master Data File
MRC	Maintenance Repair Code
NAVICP	Naval Inventory Control Point
NAVSUP	Naval Supply Systems Command
NIIN	National Item Identification Number
PPR	Planned Program Requirements
QQ	Quantile-Quantile
RC	Recoverability Code
RII	Repair Item Indicator
RLINK	Repairables Linkage
SDR	Supply Demand Review
SM&R	Uniform Source Maintenance and Recoverability File
SMA	Supply Material Availability
TIR	Transaction Item Reporting
UICP	Uniform Inventory Control Program
WRST	Wilcoxon Rank Sum Test
WSF	Weapon System File

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As Jerry Garcia and company once espoused, “What a long strange trip it’s been.” Having little notion of just what Operations Research was at the start of my studies, I can now say that I am better prepared for whatever things may come at their completion.

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EXECUTIVE SUMMARY

Integrated business operations frequently exchange information across databases and draw information from common sources. An error existing in a source file can be replicated with every transaction, with every table created, and with every query conducted that accesses that file. Thus, source-file errors propagate into subsequent operations or decision-support applications. Failure to detect or correct an existing source-file error can result in end users of information, such as executives or analysts, basing their decisions on faulty information with possibly adverse results.

Because the effects of data errors can be difficult to isolate, addressing data-quality shortfalls often is assigned low priority, despite research findings that the cost of data-quality shortfalls can range from 10 percent to 25 percent of an organization's operating budget. Given the large volume of transactions conducted and breadth of line items managed by the U.S. Navy's inventory system, even a small percentage-wise cost due to data errors can have a large fiscal impact. For example, a one-percent loss in Naval Inventory Control Point (NAVICP) inventory operations due to data errors would have been equivalent to $42 million in the cost of aviation spare parts in fiscal year 2002 alone.

In fiscal year 2003, NAVICP managed more than 350,000 line items in its inventory. In order to explore the effects of data-quality shortfalls on a related set of material, the thesis research focused on inventory items related to the F404 engine group, which consists of 669 line items. Across the United States and allied military services, there are over 3,700 F404 engines in use on 1,458 F/A-18 Hornet aircraft alone The F404 engine represents a high-use, high-demand system of critical importance to U.S. Naval aviation and to the aviation support of its allies.

The data-quality improvement program at NAVICP conducts monthly audits on its major inventory management databases, checking for logical errors between data fields. To assist NAVICP in prioritizing resources allocated to error correction, this thesis describes a means of evaluating what impact, if any, specific error types may have

on its inventory operations. In the course of the thesis research, a link between error types and excessive backorder quantities was found.

To categorize conditions of backorders, a means of identifying problematic backorder items, using a new inventory performance measure referred to as the Backorder Persistence Metric (BPM), was developed. BPM is a count of the number of months that an inventory item exhibits a backorder-to-demand ratio in excess of a threshold during a specified time period. For inventory items in the F404 engine group, BPM values were used in statistical testing in order to identify error types that were associated with higher incidences of backorders. This analysis revealed that one error type from the Master Data File (MDF) audits yielded significantly larger backorder quantities on affected items than those items without this error.

Potential savings in inventory-system costs associated with reducing excess backorder quantities for four F404-related items that exhibited this error were estimated to be over $193,000 based on backorder reductions for a one-month period. This amount represents 14 percent of the monthly purchase demand or as much as 42 percent of a repair-purchase mixed cost model. Realized savings would not be apparent until completion of the first post-error correction procurement cycle.

A BPM-based analysis allows NAVICP to set a user-defined threshold for excessive backorders. This allows inventory managers and data quality specialists to select criteria that are consistent with inventory management objectives. BPM analysis can also be applied to any set of inventory items provided that the requisite information is available.

Statistical testing using Supply Material Availability (SMA) also provides insight into the relationship between MDF data errors and the availability of inventory material. The same MDF error type exhibits a statistically significant relationship with low SMA values, consistent with the result of testing using BPM.

In light of these finding, the following three recommendations are made to improve the data quality enhancement effort at NAVICP:

1. Top priority should be given to the correction of major database errors that are strongly related to high BPM or low SMA.

2. In addition to the use of SMA, adopt BPM as a metric for inventory performance with respect to data quality improvement activities at NAVICP.

3. Adopt shortage-cost avoidance as a criterion for prioritization of data-quality remediation efforts.

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I. INTRODUCTION

Monitoring the accuracy of data in the Information Age has become a priority for enterprises of all sizes. In the universe of business applications, there are few systems as concerned with data quality as large-scale inventory management processes. Integrated business operations frequently exchange information across databases and draw information from common sources. An error existing in a source file can be replicated with every transaction, with every table created, and with every query conducted that accesses that file. Thus, source-file errors propagate into subsequent operations or decision-support applications. Failure to detect or correct an existing source-file error can result in end users of information, such as executives or analysts, basing their decisions on faulty information with possibly adverse results.

Many enterprises have little grasp of the prevalence of erroneous data in their information systems (Dubois, 2002). A data system starting with perfectly accurate records will, over time, face deterioration in the quality of its data, unless remedial measures are in place. Unchecked by quality controls, it is estimated that corruption of otherwise accurate records occurs at a rate of about two percent per month (Dubois, 2002). Because the effects of data errors can be difficult to isolate, and because they usually occur outside of the immediate view of decision makers, addressing data-quality shortfalls often is assigned low priority, despite research findings that the cost of data-quality shortfalls can range from 10 percent to 25 percent of an organization's operating budget (Redman, 2001). Given the large volume of transaction records maintained by the U.S. Navy's inventory system, even a small percentage cost due to data errors can have a large fiscal impact. For example, a one-percent loss in NAVICP inventory management operations due to data errors would have been equivalent to $42 million in the cost of aviation spare parts in fiscal year 2002 alone (NAVICP, 2003).

The purpose of this thesis is to measure the effects of data errors in a major information file that is used in the management of inventory at the Naval Inventory Control Point (NAVICP) in Philadelphia, PA. In particular, this thesis focuses on the effects of these errors on the prevalence of backorders across a set of related inventory

material. In order to evaluate the influence of specific error types on backordered requisitions, a metric that we refer to as "persistence" is defined. By applying statistical testing to a data set that was constructed to support the thesis research, error types identified in the information file are classified by their effects on the procurement process. By identifying error types that adversely influence NAVICP performance, inventory analysts can gain insight that will help them to prioritize their data quality improvement efforts.

A. BACKGROUND

Within the Department of the Navy, the Naval Supply Systems Command (NAVSUP) provides U.S. Naval Forces with logistical support. The principal source of readiness for U.S. Naval Forces, NAVSUP manages the logistics programs necessary for continued afloat operations. As NAVSUP's primary activity for weapons systems support, NAVICP exercises control over 350,000 different line items of repair parts, components and assemblies that keep Naval ships, aircraft and weapon systems operating. NAVICP's stated mission is

> to perform program support inventory control point functions including integrated logistics support planning and execution, maintenance of logistics support data, inventory management of assigned secondary items, weapons systems, end items and equipment for Naval ships, submarines and aircraft (NAVICP, 2002).

NAVICP is located at two main facilities, in Mechanicsburg, PA and Philadelphia, PA, which manage non-overlapping functional areas of ship, submarine, and Naval aviation material. In this thesis, attention is focused on inventory activity in Philadelphia. NAVICP will refer to the Philadelphia facility unless stated otherwise.

In its role as the Navy's principal information broker for Naval logistics data, NAVICP is tasked with maintaining the Navy's major weapons system inventory data, and with ensuring the integrity of the data contained therein (NAVSUP, 1992). NAVICP has recognized that data quality management is an essential component of the organization's supply chain management operations (Harnitcek, 2002). In 1979, NAVICP established the Database Integrity Center to perform data-quality analyses on

item records, which ultimately led to the development of diagnostic tools that remain in use (Orr, 2003b).

In June 2002, the Database Integrity Center was reorganized into the Data Integrity Management Center to oversee the promotion and evaluation of data quality throughout the NAVICP information warehouse. DIMC is organized into three groups, each working on different functional aspects of Data and Information Quality (DIQ). One group works in business and functional analysis to identify error occurrences, one in operations research and quantitative analysis to measure the effects of error instances, and one in error review and correction (Orr, 2003a).

At the time that this thesis was written, DIMC was preparing for the gradual replacement of NAVICP's legacy software systems with an Enterprise Resource Planning (ERP) database management system. ERP consists of a relational database system that features a single central data file from which all business applications—whether financial, purchasing, sales, inventory or planning—share the same information. The ERP software system chosen by the Navy was scheduled for testing with two pilot weapon system families in June 2002, with increasing implementation starting in January 2003. While the initial tests of the sample systems were deemed successful, further implementation of the ERP system had been delayed at the time of this writing in order to assess the gains made and lessons learned among other Navy commands.

Data interoperability and accuracy shortfalls are recognized as the most serious barriers to the successful accomplishment of the ERP implementation project (Dobbs, 2002). DIMC is involved with preparing the data for each weapon system for migration from the legacy system into the ERP architecture. Presently, DIMC's evaluative and corrective activities are performed on an *ad hoc* basis, based on ERP implementation scheduling, inventory manager feedback and office expertise.

The Data Administration office at NAVICP is responsible for tracking the accuracy of information contained in the NAVICP legacy system data files, utilizing a diagnostics program that steps through each data record from four major databases that are described in Section C of this chapter. The Data Administration office performs a

field-by-field evaluation of record accuracy based on logical rules developed by DIMC. The error detection software is run monthly, results of which are reported to the program managers of each weapons system. These error lists, combined with the data-base information held on items that are linked to the errors, are the primary sources of data for the thesis research.

B. DATA SELECTION

In fiscal year 2003, NAVICP managed more than 350,000 line items in its inventory (Harnitcek, 2002). In order to explore the effects of data-quality shortfalls on a related set of material, the thesis research focused on inventory items related to the F404 engine group, which consists of 669 line items. Because of the importance of the F404 engine group, it was recommended by NAVICP officers as a high-interest system in which to study the effects of inventory data errors. In addition to powering the Navy and Marine Corps fleet of F/A-18 (models A through D) aircraft, the F404 engine is also used in the Air Force F-117 Stealth Fighter that has been sold to allied nations throughout Europe and Asia (Boeing, 2002). Recently, the F404 was selected for the X-45B Unmanned Combat Air Vehicle program scheduled to fly in 2005, sponsored by the Defense Advanced Research Projects Agency and the U.S. Air Force (GEAE, 2002a). Across the United States and allied military services, there are over 3,700 F404 engines in use on 1,458 F/A-18 Hornet aircraft alone (GEAE, 2000). Additionally, the F414 engine used in the F/A-18 E and F model Hornets, of which some 548 aircraft are scheduled for production with engine deliveries from 2003 to 2008, is the direct descendant of the F404 with parts common to both under NAVICP management (GEAE, 2002b). The F404 engine represents a high-use, high-demand system of critical importance to U.S. Naval aviation and to the aviation support of its allies.

C. AN OVERVIEW OF DATA ERRORS

The Data Administration office at NAVICP conducts its analysis of database integrity by assessing four databases: the Master Data File (MDF), the Weapons System

File (WSF), the Uniform Source, Maintenance and Recoverability (SM&R) File and the Repairables Linkage (RLINK) File (Alcorn, 2002):

- The MDF contains general information on all the items under NAVICP management and is the major data provider for the inventory control program (NAVICP, 2002).
- The WSF is designed to interconnect the components of each weapons system in the NAVICP inventory. It provides the capability to identify each part, equipment system, or subsystem to its next higher or next lower application.
- The SM&R File consists of a listing of codes associated with the procurement source and maintenance information for NAVICP items. It is extracted from MDF data fields and duplicated for quick reference.
- The RLINK File details connections between the item data contained in the MDF and the respective assembly in the WSF to which it belongs.

As all the line items associated with the F404 group belong to a single mechanical system, this imposes a limitation on the error types that occur. The information provided by the WSF would be of limited value given the single-system nature of the F404 engine group. Since the data contained in the RLINK and SM&R files are specialized duplications of data extracted from the MDF, it seemed reasonable to exclude them from the thesis research, particularly given the lack of errors from those files in the August 2002 error listings. For these reasons, the thesis research focused exclusively on errors associated with the MDF.

The most recent error listing at the time that this thesis was written (February 2003) indicated 129 "active" error types. An active error is one for which DIMC has created a set of evaluation rules, assigned a code, and submitted to Data Administration for inclusion in error detection activity. The set of active error types does not remain static over time: DIMC eliminates error codes when they are deemed resolved, and adds new error types as required. In the August 2002 error listing, there were 96 active error types, 90 of which were associated with the MDF. For the F404 engine group in the August 2002 error listing used in this research, 23 of the 96 error types were represented, of which 22 were associated with the MDF.

D. EFFECTS OF DATA ERRORS ON INVENTORY OPERATIONS

Upon close examination it becomes clear that errors in the major data files can have significant effects on inventory operations. The following example illustrates the potential effect of an MDF data error on down-stream inventory operations. The August 2002 error audit conducted by DMIC assigned the error code “AP” to a line item[1] associated with a manifold in the T700 engine for the SH-60 Seahawk helicopter. This error code indicates that three different fields of the MDF contained values that were not consistent: (1) the Maintenance Repair Code (MRC), which identifies the level of maintenance activity authorized to perform repair actions on an item and is used to validate an item’s status as repairable or consumable (disposable); (2) the Recoverability Code (RC), which indicates the appropriate maintenance level authorized to repair an item or to dispose of an unserviceable items; and (3) the Repairable Item Indicator (RII), which is extracted from another data source and indicates whether an item is repairable or non-repairable (consumable). In the present example, the RII identified the item as repairable, but both the MRC and the RC contained values indicating that the manifold is not authorized for repair and is a non-repairable item, respectively.

Because the repairable status of an item influences supplementary data fields that provide inputs to procurement and repair applications, the inconsistent designation can propagate errors throughout decision analysis outputs. This may lead to the purchase of too many new items caused by disposal (as opposed to repair) of the item, or to a failure to allocate sufficient resources to repair material held at maintenance depots. The error may be costly to the Navy, either in monetary terms, or in a lack of critical material needed to execute its missions.

Upon further investigation it was ascertained that the manifold is a repairable item. Although the manifold is in the Naval inventory, it is under the management

[1] Manifold, Pressurization assembly, National Item Identification Number: 01-120-7538

responsibility of another military service, possibly the United States Army, which uses the H-60 aircraft extensively. It is possible that, during the transfer of responsibility for the item from the Navy to the Army, not all the fields associated with changing ownership for the item were correctly updated.

The example presented above illustrates how an error in a major inventory data file can adversely affect the quantity of material available to execute critical missions. Ensuring adequate levels of material within budgetary constraints has been recognized as one of the most serious problems facing the Navy (Finley, 2002). In an inventory system, a *backorder* refers to a request for material where the item is not immediately available in the quantity required but the obligation to provide the material remains. A detailed discussion of backorders in the Naval inventory system is presented in Section C of Chapter II. In many large, commercial inventory systems the existence of backorders is neither unusual nor problematic; however, backorders for Navy material can assume a heightened degree of concern. The result of a backorder for a critical component may be a non-mission capable weapon system. In the case of the over 3,700 F404 engines in use, the lack of a single mission-essential item can lead to an idled aircraft, an under-equipped squadron and unsupported missions.

The requirements determination process, by which NAVICP sets inventory policy, is a multifaceted operation. The presence of errors in the major data files, such as the MDF, can adversely affect decision-making at all levels. Missing or erroneous data can delay the execution of procurement decisions, as automated procedures must be overridden by manual review. Stocking material at lower levels than required due to these errors aggravates problems caused by backorders, a situation made worse if additional demands for an item arrive before the faulty data is corrected.

E. THESIS OBJECTIVES AND ORGANIZATION

The purpose of this thesis is to develop an analytical approach to assist DIMC in the prioritization of its data quality effort, based on identifying statistical relationships between data errors and corresponding backorders for items under inspection. By

exploring the connection between data errors and backorders, it will be possible to identify error types that have a plausible connection to faulty inputs in the requirements determination process. The relation of backorders to data quality will be more thoroughly explored in Chapter II.

Although the focus of the thesis is on the 669 items that comprise the F404 engine group, the underlying methodology is applicable to any class of inventory items. While the explicit quantification of costs associated with backorders is an unresolved issue in the open literature of inventory management, there are accepted methods for the estimation of costs associated with backorder quantities (Tersine, 1998). A value for return on investment as a result of data quality improvements will be estimated by calculating the imputed cost per unit for backordered items determined to be in excess of normal operations due to the presence of errors in the data file.

By identifying statistical relationships between MDF-occurring error types and disproportionate backorder quantities, it will be possible for DIMC to compile a list of error types and the items they affect for detailed review. This listing can be accomplished by a "backorder persistence" metric that measures the number of months over a given time period that a line item has experienced backorders in excess of a user-defined parameter. Using a nonparametric statistical test, the backorder persistence metric can be evaluated to detect error types that are associated with high backorder rates. These error types should be given priority for error remediation.

The objectives of this thesis are as follows:

1) Perform a domain review of the F404 system sample data set to establish the key characteristic data elements of the item records in major inventory data files, and their corresponding error types.
2) Conduct an analysis of the F404 system sample data set to evaluate patterns of error occurrence and the potential influence of each error type.
3) Develop a metric for evaluating backorder rates.
4) Identify error types that are associated with high backorder rates.

The remainder of this thesis is organized as follows: Chapter II provides an overview of the Naval supply system requisitioning process and the means by which data errors can impact operations. Data quality is defined and discussed in detail. Chapter III describes the data used in the thesis research. Chapter IV discusses the techniques used to evaluate backorders in relation to error types, for which a new inventory performance measure, referred to as the "Backorder Persistence Metric" (BPM), is defined. Supply Material Availability, an inventory performance metric used by NAVICP, will be presented for comparison with the BPM. Chapter V presents conclusions based on the research findings and offers recommendations regarding the future direction of data correction efforts.

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II. REQUISITIONING AND DATA QUALITY

A. REQUISITIONING BASICS

Be it a ship, aircraft squadron, maintenance depot or shore facility, a Naval field activity frequently submits orders to fill its material needs. The need for material arises due to a number of factors, the most common being equipment failure, scheduled maintenance, or replacement of local stock. The material order request (known as a requisition) is transmitted from the field activity by means of an automated electronic form that is entered into supply system management databases. The Naval supply system consists of local support centers, regional distribution depots and the inventory control points (NAVICP). When a requisition is filled, the warehouse management office requires a replenishment of its own stock and submits another requisition for this purpose. Ultimately, the requisition is recorded into the databases at NAVICP for logistics management purposes. The execution of this sequence of tasks requires interfacing with many database files as a requisition continues on its path through the system.

B. DATABASE STRUCTURE

For organizing the large volume of repair material, and for tracking the historical demand and descriptive data, NAVICP maintains several large databases for use in the Uniform Inventory Control Program (UICP) management software system. At the completion of its initial development phase in 1967, UICP consisted of two distinct subsystems, the Weapons System (WEPS) and the Inventory Control System (ICS). The WEPS database, with the WSF as its main functional file, contained installation and configuration data for weapons systems. Likewise, the ICS database, built on top of the MDF discussed in Chapter I.C, was utilized for requirements determination and the processing of asset reports, including material movement transactions, customer requisitions, and the preparation of purchasing documents. Today, the Master Data File and the Weapons System File remain two of the largest data files in continuous use.

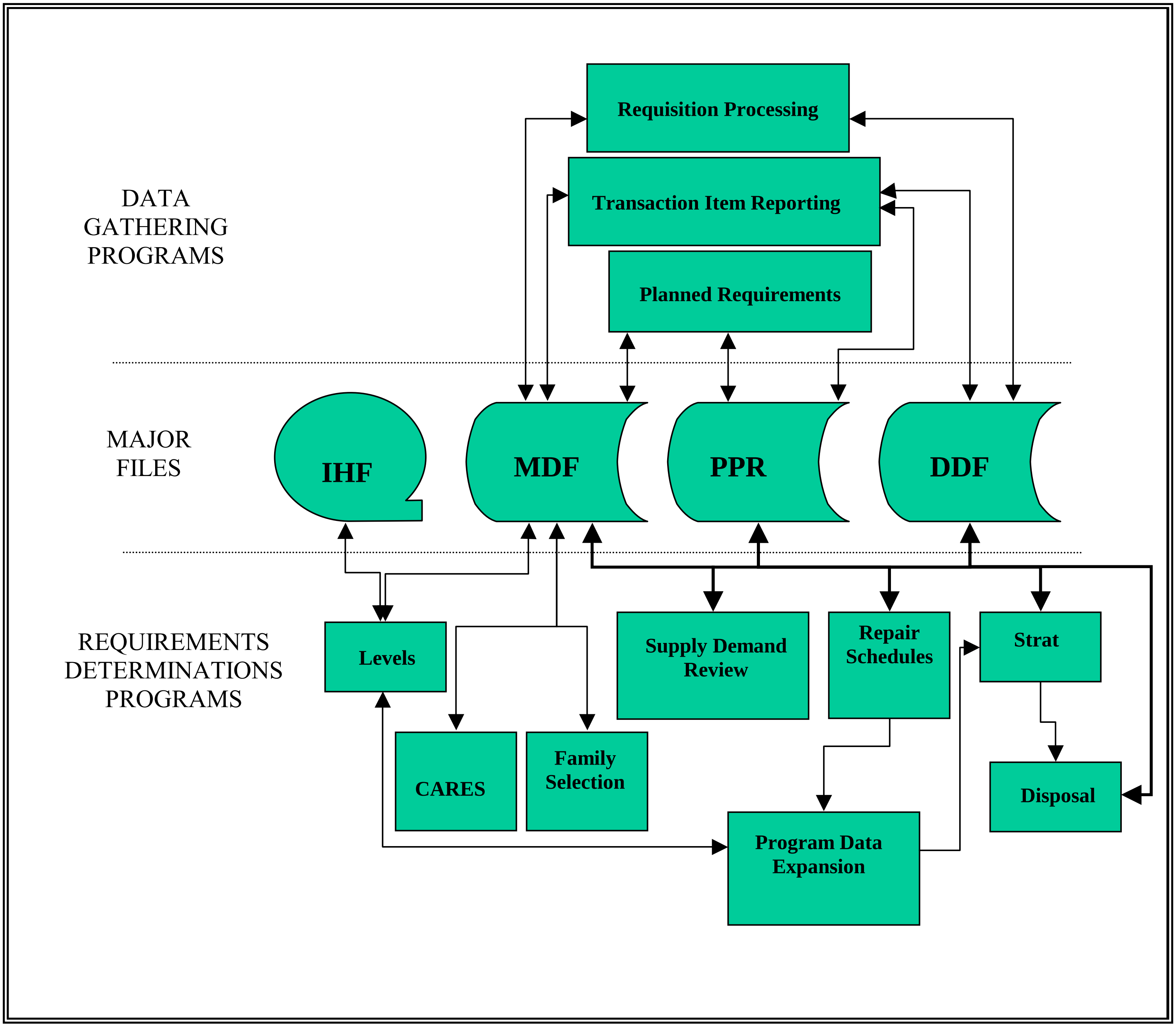

Figure 2.1: Simplified UICP System Requirements Determination Model Indicating Data Flow Among Databases and Applications

(From: NAVSUP, 1992)

UICP eventually developed into a tiered software system composed of six databases, and seventeen applications built around functional business areas. In this system, the MDF retains its role as the primary information file for all material, containing descriptive data on each line item maintained by NAVICP, indexed by a unique National Item Identification Number (NIIN[2]). Due to evolving needs for specialized data, each record in the MDF has grown to contain more than 400 Data Element Number (DEN) fields while adding new records to accommodate new line items. In summary, the MDF has become a data matrix, approximately 610,000 by 400 in size.

In Figure 2.1, a simplified model of the UICP database management system is presented. The model flowchart shows the relationships between key functions and files involved with the requirements determination process, in which the MDF is seen to play a central role. Details of the model elements are presented below to give insight into the potential for error propagation throughout the Naval inventory management system. These elements are categorized as Major Files, Data Gathering Programs and Requirements Determination Programs. Although the relationship of the applications with respect to data interchange in the MDF is our primary focus, other aspects of the UICP model are also described.

1. Major Data Files

The four major data files utilized by UICP are the Master Data File (MDF), Planned Program Requirements (PPR) File, Due-in/Due-out File (DDF), and the Inventory History File (IHF). The PPR File contains an entry for each NIIN that has one or more planned requirements established. These planned requirements are essentially a placeholder for quarterly demands that would not otherwise be forecasted within the UICP model, such as large scale non-recurring purchases that are known well in advance. The DDF contains an item entry for each outstanding action for all current assets in the supply system, such as requisition referrals from NAVICP, procurements, and movement

[2] NIIN is a nine-digit label that uniquely identifies each item in the Federal Supply Catalog.

of material into and out of the repair process. The IHF maintains a historical inventory record for each item under NAVICP management, covering the previous eight calendar quarters, with summary data available for the previous five years.

2. Data-Processing Applications

Three functional groups of software applications input data into the UICP system; each of them draws information from the major data files, particularly the MDF. The first, Requisition Processing, receives requisitions directly from customers. There are circumstances in which NAVICP is the first source of supply for customers rather than a local stock point. They include requisitions to centralized purchasing programs, ordering of an item with restricted issue, and requisitions made directly to NAVICP when the local stock point is out of stock and the stock point is not authorized to procure the item locally. When a direct requisition is received, the Requisition Processing program examines the MDF data to locate available assets or a suitable substitute; should there be no items on hand, the application determines whether the demand is to be met using a spot (one-time) procurement or a repair, or placed on backorder

The Transaction Item Reporting module (TIR) is the means by which the UICP databases obtain most of the information concerning changes to the distribution and availability of assets throughout the Naval supply system. As noted earlier, the Naval supply system is a multi-level distribution network. When one of the local stock points issues or receives material, it files a transaction item report that is received by UICP for demand counting and reordering purposes. Additionally, the TIR processes special documents submitted by the NAVICP item manager, such as adjustments to inventory, quantities under repair, material due in from procurement and planned program requirements. Essentially, the TIR is used as the primary input for transactions that update the major data files, particularly the MDF.

The third data-processing application, Planned Requirements, receives inputs from the PPR file, aggregates all PPR data for a single item into the summary requirement, and serves as a mechanism to track non-recurring demands on items. Non-recurring demand refers to one-time requirements, such as new construction or planned

overhauls, which are kept in a separate file from recurring demand requisitions. Non-recurring demand requirements are not used by UICP to forecast recurring demand.

3. Requirements Determination Programs

Data that have been collected and stored are used by UICP to support its procurement decision-making. The requirements determination process is the central focus of the Navy logistics system, driving the budgeting, procurement, physical distribution and information technology systems (NAVSUP, 1992). The eight programs depicted in Figure 2.1 are the essential applications for this process. Each of these programs is described briefly below.

(1) Cyclic Levels and Forecasting ("Levels") is used to compute forecasts and to set inventory levels for items under NAVICP management. Combining information stored in the MDF with previous demand forecasts, the Levels application computes quarterly forecasts of system recurring demand, requisition frequency, procurement and production lead times, repair turnaround times, repair survival rates and wearout rates. Results of these computations are entered back into the MDF and utilized for budget planning and stock distribution. This application updates key inventory management parameters (order quantity, reorder level, safety level, etc.) on a quarterly basis.

(2) Supply Demand Review (SDR) is the daily operations program of UICP. This application is used to compare assets and requirements, compute system purchases, and screen supply activity for manual review on a continual basis. Contractor performance information is contained in the MDF procurement lead-time data fields. The procurement lead-time data provides the basis for decision making when expediting procurement orders of critical items in a manual review process. An important data-quality issue in requirements determination accuracy is that procurement lead-time values are modified when a change of vendor occurs. If procurement lead-time values are not updated correctly to reflect a specific supplier, the SDR purchase quantity will either

overestimate (if actual lead-time is shorter) or underestimate (if actual lead-time is longer) the requirement.

(3) The Repair Scheduling program is used to compare the number of ready-for-issue assets to the real-time and forecast demand requirements for repairable items in order to support the management of repair actions and the redistribution of not-ready-for-issue material at maintenance depots. Repair scheduling is similar in concept to SDR, but focused on the repair process. The essential MDF data field used in Repair Scheduling computations is the depot-level repair turnaround time.

(4) The Stratification program ("Strat") provides a long-range look at projected excesses and deficiencies in material, and provides the summary management data used as the starting point for procurement and repair budget determination. Stratification uses asset information from all four major data files, the MDF in particular. Stratification includes a data validation routine that indicates the need for manual review if parameter values for assets, requirements, deficiencies, or forecasts are exceeded.

(5) Program Data Expansion associates program data for a weapon system or unit assembly with its component parts. Program data consist of numerical parameters that are used in the operation and maintenance of a weapon system or item under management over a specific time period, depending on the application. Examples of program data are the allowable flying hours for an aircraft, and the number of a given weapon system in use, such as the number of F/A-18 aircraft in the Navy inventory. Of importance to this research, NAVICP utilizes program data on maintenance cycles and overhauls for aircraft engines (including the F404) in its forecasting models.

(6) The Family Selection program assigns a family group code that is used to cross-reference items within a group. In systems-level inventory management, a "family" is a group of two or more items that are recognized as having an interchangeability or substitutability relationship with each other. Family relationship is an important data element of the MDF. UICP utilizes these codes to consolidate demand observations for use in determining inventory level requirements.

(7) The Disposal program calculates a retention limit for inventory items, which is the quantity above which it is not cost-effective to maintain such material in inventory. Because it is uneconomical to retain excess material, a procedure is needed to identify items that are eligible for disposal. The Disposal program refines its disposal recommendations down to specific assets and locations in the Naval supply system.

(8) The Computation and Research Evaluation System (CARES) is an application designed to provide NAVICP with a tool to analyze and evaluate alternative inventory management policies. Using data from the MDF, CARES makes projections of stock levels for five different inventory policies and compares the values with those generated by UICP. Additionally, CARES generates statistics on individual items such as annual value of demand, on-hand assets, contracts, backorders and time horizon requirements, as well as summary statistics on the value of assets on hand grouped by subcategories.

Figure 2.1 and the foregoing discussion illustrate the integral role played by the MDF across a wide range of UICP applications. There is no application or program within UICP that does not rely on MDF data. Proper management of the Naval inventory system, which is responsible for the procurement and repair of material valued in the tens of billions of dollars annually, depends critically on the integrity of this data file.

C. BACKORDERS DEFINED

When material on hand is insufficient to meet the demands or orders required, an out-of-stock condition occurs. The nature of military inventory management is such that there is no alternate source of supply for the material required, so the “customer” must wait for delivery of the item from the supplier, a situation known as a backorder (Tersine, 1998). With respect to data quality, a backorder may be caused by faulty information in any of several data fields in the major data files.

In addition to basic inventory management information relating to cost, unit of issue, source of supply or reorder level, the MDF contains information on relationships among collections of items, including circumstances where multiple items are combined

into an assembly. At different levels of maintenance, different items are required to effect a repair to the overall weapon system. For example, a field activity maintenance action may call for replacement of a large assembly given the failure of an individual component. The damaged assembly would be forwarded to a more capable or "higher level" maintenance activity, such as a commercial depot, that would repair the assembly by replacing the broken component. In this case, the field activity would then requisition a new assembly for its inventory and the depot would requisition a new component item to complete its work. The information indicating the maintenance level allowed to procure an item is indicated in an appropriate MDF record field. In the event that a field activity was to requisition an individual component, the request should automatically be redirected as an order for the complete assembly. Should the assembly relationship be misstated so that the component is listed as a stand-alone item, a complete assembly in available stock would not be issued to fill the order, and a backorder for the component item would be created (Orr, 2003a). A complicating factor for this problem lies in the tracking of demand: while an assembly was required, and only the component item was ordered, the forecast demand for the assembly will now be underestimated and the forecast demand for the item will be overestimated.

Likewise, items that have similar functions in different systems can serve as substitutes for each other if validated through an engineering review process. If a requisitioned item is out of stock, but a validated substitute item is in stock, the alternate item is issued to fill the order. A data-quality problem arises if the engineering review is not correctly entered into the MDF, so that the alternate NIIN field either is empty or contains erroneous information. In either case, backorders may result. If the field is empty, the MDF would fail to link the requisition to a possibly available asset of the substitute item, thereby immediately creating a backorder for the initial item (Orr, 2003a). Similarly, if the field contains an erroneous entry, the initial requisition may be filled by the wrong item, thereby requiring another order by the field activity and removing the incorrect item from use by another party. The second requisition for the initial item would be coded for manual intervention, which delays filling the order as personnel try to determine the cause of the error.

Although backorders are not necessarily symptomatic of an error-prone database, excessive and enduring backorders may have causes other than periods of unusually high demand. Errors in databases used in inventory management should then be considered as an alternative cause. There is an abundance of scenarios in which backorders may be caused by erroneous inventory data.

D. CHARACTERISTICS OF DATA ERRORS

The Data Administration office at NAVICP conducts data-quality audits on the first day of each month, targeting the four major databases (MDF, WSF, SM&R File and RLINK File) as discussed in Chapter1 Section C (Alcorn, 2002). After processing these four databases with diagnostic software, an output file for each of the databases is created. Each output indicates the number of records screened, an itemized listing of the error codes with counts of each, and the rationale for the count.

There were 23 unique error types found in the F404 item error listings of 01 August 2002. Because 22 of the 23 error types present were contained in the MDF error output, and for the reasons presented earlier in Chapter I Section C, the remainder of this thesis is focused specifically on those errors occurring in the MDF. Given the number of records present and the changeable nature of many of the important data fields in the MDF, it is not surprising that it contains the largest number of errors among the four databases tested. It is noted that the only error type not associated with the MDF was found in the WSF.

Figure 2.2 presents a Pareto chart that shows the frequency of error types for items in the F404 engine group. As indicated by the chart, over 92 percent of the data errors from the 01 August 2002 data-quality audit were associated with only eight error codes. It is illustrative to analyze some of the most frequently occurring errors to better understand their origins. The three most frequently occurring error codes are discussed below in separate subsections. A more extensive discussion of those error codes is provided in Appendix A.

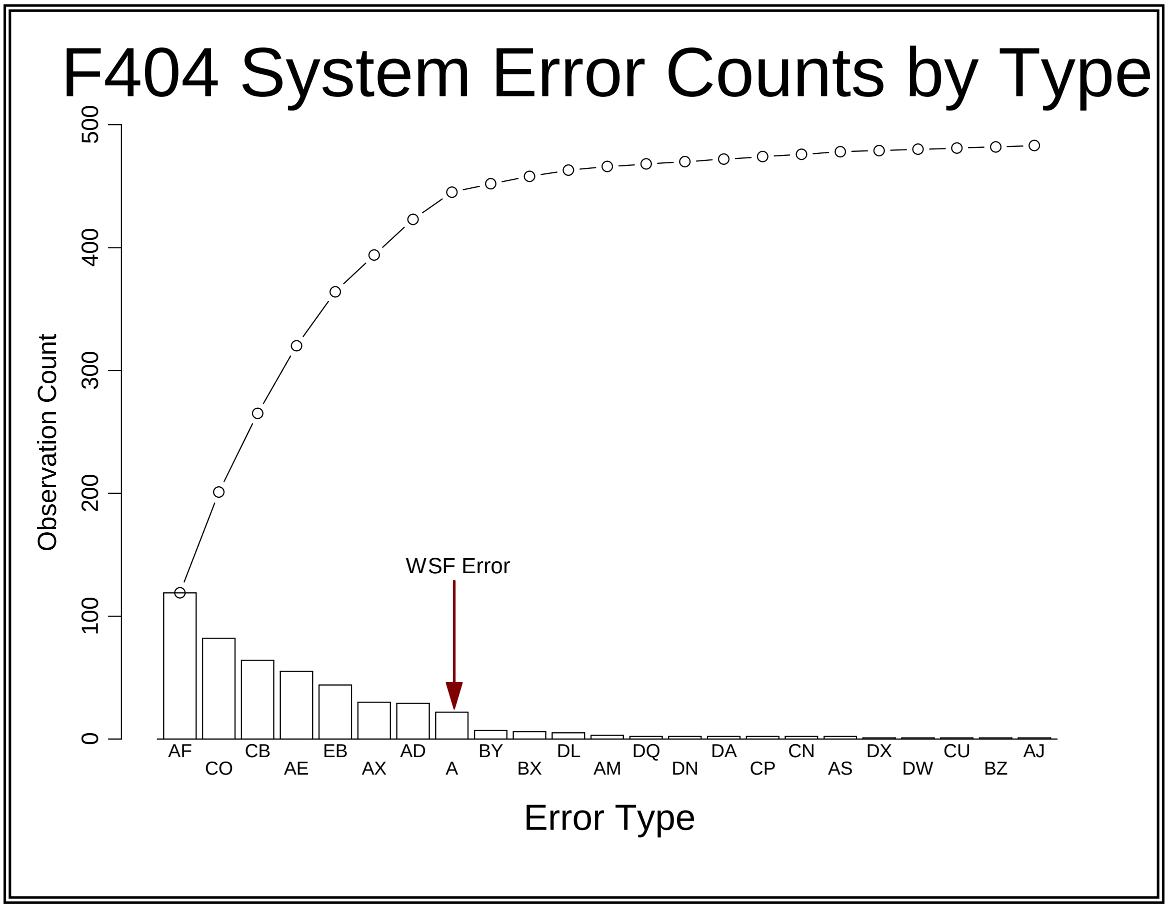

Figure 2.2: Breakdown of error types in descending order by number of NIINs affected in the F404 Engine System as of 01 August 2002.

1. Error Code "AF"

Error code "AF" indicates an error in the linkage between the manner in which an item is procured and the vendor from which the item is purchased by NAVICP. Purchases of an item are restricted to sources as specified in technical documentation for the system in which it functions. Error code "AF" indicates that there is conflicting information regarding these restrictions. For example, a reference in one field may indicate that an item is to be purchased from a restricted source, but another field may lack this information. In the automated procurement sequence, this would lead to rejection of the requisition, and require manual intervention to complete the purchase. Manual intervention requires research to identify the proper supplier for the item, and

may require a review for another qualified source, which inadvertently extends the time required to complete the requisition (Heigh, 2003).

2. Error Code "CO"

While the "AF" error applies to the source of an item, the "CO" error applies to the procuring authority. As in the case of the "AF" error, the "CO" error may arise if an item is not registered in the Federal Supply Catalog in a restricted category, but has restrictions on the source of supply. The difference between the two error types is that NAVICP is not the purchaser of the item with the "CO" error. This is illustrated with an example taken from the August 2002 error listing, in which a fuel pressure valve was identified with a "CO" error. The valve was classified by NAVICP as a high-demand and high-value item, indicating frequent purchases and amplified management attention. The Defense Logistics Agency (DLA) manages the supply of this valve, but NAVICP retains the technical documentation for the system that identifies the approved suppliers for the item. Because of the erroneous assignment of management responsibility for a procurement restricted item, the time required to complete procurement of the valve is increased, due to the need for interaction between DLA and NAVICP to ensure that the proper source is contracted to supply the item.

3. Error Code "CB"

Error code "CB" indicates a mismatch between an item application code and the data field that it references. In one of the fields evaluated, a code specifies whether the field contains either information on the family to which it belongs, or if the item is attached to a special program. Related fields are evaluated to determine which instance applies. The "CB" error occurs if the related fields hold values that are contrary to the nature of the application code. If the item belongs to a special program but the code references the assembly of which the item is a component, then computations for demand forecasts and procurement lead-time may not be accurate. This can lead to the item either being over- or under-purchased, relative to its demand.

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III. DATA USED IN RESEARCH

A. SOURCES OF DATA

To conduct analyses on data errors related to the F404 engine group, three sources of data were used: (1) basic item-descriptive information, taken mainly from the Master Data File (MDF), which contains records on each item under review; (2) the corresponding backorder history for those items; and (3) data from diagnostic edits. NAVICP provided the data used in the thesis research in the form of Excel® spreadsheet files, which were imported into S-Plus® statistical analysis software. Each of the three data sources is described in separate subsections below. Appendix B provides a detailed description of the fields contained in each of the data sets that were used in the thesis research.

1. Basic Item-Descriptive Data on the F404 Engine Group

This data set consisted of five fields, four of which were extracted from the MDF as of August 2002. The remaining field, Supply Material Availability (SMA), was obtained from a separate source. In total, there were 669 records in the data set, with each record representing a distinct item in the F404 engine group. Each of the fields is briefly described below:

a) **Item Number**: The National Item Identification Number (NIIN) label for the item.

b) **Quarterly Demand**: Expected number of units of demand for the item to be received by the system per quarter, as determined by the UICP Levels application. It is a forecast value based on previous demand observations.

c) **Item Price**: Replacement price for the item when procured by NAVICP. It is initialized with an estimate for items recently added to inventory management at NAVICP and updated with the price of the most recent purchase.

d) **Repairable Flag**: An indicator of whether an item is repairable or consumable. A repairable item is transferred to a depot maintenance

activity for repair upon failure. There are special handling rules and price structures for repairable items that distinguish them from consumable items, which are discarded upon failure.

e) **Supply Material Availability (SMA)**: Proportion of requisitions filled from available stock over a one-year time period for the inventory item. In this thesis SMA values for fiscal year 2002 were used. SMA is an important performance metric used by the Naval supply system. A more detailed discussion of SMA is deferred to Chapter IV.

2. Backorder History Data

The backorder history file was formatted into a data set containing 669 records of 17 fields. Each record in the backorder history file corresponds to a unique inventory item in the F404 engine group, showing the quantity of backorders by month over the fifteen-month period from June 2001 through August 2002. Backorders were defined in Section C of Chapter II. Of the 669 items in the F404 inventory, only 171 had any recorded backorders over the fifteen-month time period. Additionally, only 18 items had non-zero backorder quantities in each of the fifteen months while 48 of the items experienced a single month with backorders over the same period.

3. Error Incidence Data

The error incidence data set was extracted from the results of the monthly data integrity audit conducted at NAVICP in August 2002. This information was formatted into a data set containing 669 records of 25 fields. Each record corresponds to a unique inventory item in the F404 engine group, and gives the incidences of errors observed in each of the 23 MDF error categories associated with the F404. Only 238 of the items exhibited at least one of the error types. Further description of the error incidence data set is provided in Appendix B.

B. OVERVIEW OF ERROR INCIDENCES

Table 3.1 provides a simple cross-tabulation of the 669 inventory items associated with the F404 engine group, by the incidence of errors in the Master Data File and the occurrence of at least one backorder over the fifteen-month period from June 2001 to August 2002. For items with at least one MDF error, 22 percent (53 out of 238) experienced at least one backorder during the fifteen-month period, while 27 percent (118 out of 431) of items without detected errors experienced at least one backorder over the same period.

Table 3.1: Cross-Tabulation of Error and Backorder Incidence for each item in the F404 Engine Group

	Items without Backorders	Items with Backorders	Totals
Items without Errors	**313**	**118**	**431**
Items with Errors	**185**	**53**	**238**
Totals	**498**	**171**	**669**

It should be noted that Table 3.1 does not account for the effects that multiple errors may have on backorders, nor does it account for the severity of backorders. A substantial number of items exhibited errors in more than one of the 23 error types associated with the F404 engine group, as indicated in Table 3.2.

Table 3.2: Classification of Items in the F404 Engine Group by the Number of Master Data File Errors Detected in the August 2002 Data Integrity Audit

Number of Errors	0	1	2	3	4
Number of Line Items	431	158	47	25	8

C. RELATIONSHIP OF QUARTERLY DEMAND TO BACKORDER QUANTITY

Quarterly demand is a key variable in UICP computations. An error in the MDF quarterly demand field for an item can lead to excess material being stocked or insufficient material purchased. In the latter case, recurring demands would continuously exceed on-hand supplies, leading to an accumulation of backorders. It is of interest to ask if items with higher quarterly demand tend to exhibit greater problems with backorders. Table 3.3 is provided to explore the basis for such a relationship.

Table 3.3: F404 Quarterly Demand Data Comparison

	Engines Group (excluding F404)	F404 Engine Group	F404 records with backorders	F404 records without backorders	F404 with errors	F404 without errors
Number of Items	10,913	669	171	498	238	431
Mean Quarterly Demand	26.20	165.48	423.39	77.94	130.51	185.97
Lower Quartile (25%)	0	0	0	0	0	0
Median Demand	0	0	24.99	0	0	0
Upper Quartile (75%)	0.28	29.07	90.64	7.95	7.03	45.51

The Engines Group includes all 10,913 engine-related items in the Naval supply system, excluding the 669 F404-related items under a separate column heading. F404-related items that exhibited at least one backorder during the fifteen-month period from June 2001 through August 2002, and those that did not exhibit at least one backorder during this period are described separately. Similarly, F404-related items that are associated with at least one of the 22 MDF error types identified in the August 2002 data-quality audit are separated from those without errors. Mean Quarterly Demand is an unweighted arithmetic mean of all the quarterly demand values over the respective category of items. Median Quarterly Demand is the middle value of all the quarterly demand values over the respective category of items. The Lower and Upper Quartiles represent the midpoints between the median and the smallest and largest observations, respectively.

It is immediately apparent from Table 3.3 that most engine-related items, both for the F404 and for all engines excluding the F404, have demand values equal to zero. A demand value of zero signifies that the item does not experience recurring demand that is subject to forecasting by the UICP model. Nonetheless, the F404 engine group does tend to exhibit higher demand for parts than do other engine-related line items, as seen in the

mean and the upper quartile. Likewise, the subset of F404 items that experiences backorders tends to have higher demand than F404 items without backorders.

These findings suggest that the F404 system comprises a higher-demand group of inventory items than those of other engines in the Naval inventory, and F404 items with backorders exhibit higher demand than those without backorders. It is a characteristic of inventory levels established by the UICP model that items with higher demand experience backorders at a higher rate than those with lower demand (Croll, 2003).

Comparing the mean demand for F404 items that exhibited at least one MDF data error (130.51) to the mean demand for items without such errors (185.97) suggests moderately higher demand for the latter. Applying the Wilcoxon Rank Sum Test to samples of "F404 items with errors" and "F404 items without errors" produced a Z-value of –3.79 (p-value = .0002), suggesting that demands for items in the error group are stochastically smaller than those in the no-error group (Conover, 1999).

This finding may appear to be counter-intuitive: if data errors aggravate backorder problems, should the result not be the opposite? There are, however, two factors that must be weighed in evaluating this result. One is that backorders are not the only inventory-management problem that may be attributable to data errors. Some errors may cause excessive material to be held in inventory, which is also undesirable in that it diverts resources from more pressing needs. The other is that the results presented in Table 3.3 are aggregated across 23 error types. It will be shown in Chapter IV that by taking specific error types into account some errors are strongly associated with backorders.

IV. RESEARCH FINDINGS

In this chapter, two inventory performance metrics will be discussed: Supply Material Availability (SMA), which is currently in use by NAVSUP, and a new metric that we refer to as the Backorder Persistence Metric (BPM) which is defined in this chapter. BPM is utilized to measure the influence of data errors, categorized by error type, on backorders using the Wilcoxon Rank Sum Test.

A. INVENTORY PERFORMANCE METRICS

1. Supply Material Availability

For an inventory item, SMA is the proportion of requisitions that are met over a specified time period. Each requisition counts as a success or failure to SMA, regardless of the quantity. It is important to note that repairable items are ordered one unit per requisition. Because SMA is a principal inventory performance metric used by NAVSUP (NAVSUP, 1992), it is a useful criterion for studying the effects of data errors on inventory operations.

Of the 669 inventory items associated with the F404 engine group, only 293 items had assigned SMA values for fiscal year 2002, leaving 376 line items without assigned SMA values. Several features in the calculation of SMA contribute to missing values. First, SMA is measured only for the "head-of-family item" of an assembly. If an item is a non-family head member of an assembly, an SMA value is not assigned to it.

Second, although the SMA computation is not based on the quantity of demands filled, it does use quarterly recurring demand as an input (Croll, 2003.) If there is insufficient demand within a reporting period, then no SMA value is assigned to that item. This results in SMA computations being restricted to the higher-demand items under management.

The second observation is important when evaluating the characteristics of the F404 engine data set. The F404 engine is a high-use, high-demand system that provides

substantial data for evaluating backorders based on SMA and data errors. Although only 293 out of 669 items in the F404 engine group had SMA values in fiscal year 2002, of the 171 items with at least one backorder during the fifteen month period from June 2001 to August 2002, 132 items had SMA values. Table 4.1 shows that approximately 91 percent of F404-related items with SMA values had nonzero demands in fiscal year 2002; conversely, only about 9 percent of items with missing SMA values have nonzero demands.

Table 4.1: Quarterly Demand Characteristics of F404 Items with SMA Values

	SMA Present	SMA Missing	F404 Overall
Number of Items	293	376	669
Items with Zero Demand	27	336	363
Proportion of Items with Demand Greater than Zero	0.909	0.094	0.457

Items with and without calculated SMA values are summarized in the SMA Present and SMA Missing columns respectively.

The F404 items with backorders and the F404 items with assigned SMA values exhibit higher quarterly demand than their complementary sets. It is understood that items that have a calculated SMA, and items prone to backorders, each have above-average system demands. The influence that data errors have on both SMA and backorders remains to be evaluated. An essential part of the analysis will be to determine if SMA and backorders are similarly influenced by data errors.

2. Backorder Persistence Metric

In order to analyze the effects of data errors on backorders, it was necessary to develop a measurement to express the level at which backorders become excessive. For this purpose, a new inventory performance metric was defined that bears some similarity to SMA but also has some important differences.

While there are circumstances where backordering may be economically preferable to stocking an excessive quantity of the item (Tersine, 1998), military inventory management places a high priority on operational readiness. Nonetheless, fiscal constraints mandate that some expensive, low-demand items not be stocked for immediate issue. Particularly in the case of items with forecast quarterly demand values of zero, a requisition for such items will result in backorders. For this reason, the quantity of backorders by itself does not identify items for which the number of backorders is considered problematic. It is important to compare the quantity of backorders for an item to its recurring demand (Croll, 2003).

The Backorder Persistence Metric (BPM) is a measure of the time that the ratio of quantity of backorders for an item to its demand exceeds a threshold. This backorder-to-demand ratio, denoted $\hat{p}_{x,m}$, is calculated as follows:

$$\hat{p}_{x,m} = \frac{3B_{x,m}}{D_x},$$

where: $\hat{p}_{x,m}$ = backorder-to-demand ratio for item x in month m

$B_{x,m}$ = backorder quantity for item x in month m

D_x = quarterly demand for item x.

The backorder-to-demand ratio, $\hat{p}_{x,m}$, is not defined if D_x is equal to zero, nor is BPM defined in that case.

In the present analysis, backorder quantities were provided on a monthly basis. The corresponding demand rates were provided as quarterly forecast values. To match the monthly time frame of the backorder data, the demand value was divided by three.

The next step in the calculation of BPM involves comparison of $\hat{p}_{x,m}$ to a user-defined tolerance parameter. This parameter, denoted by α, can be interpreted as the ratio of backorders, relative to demand, above which backorders are considered problematic. For example, choosing $\alpha = 2$ suggests that a backorder problem exists when the quantity of backorders exceeds twice the average monthly demand.

Finally, BPM is defined as the number of months during the period under study for which $\hat{p}_{x,m}$ is greater than α. In the thesis research, BPM was calculated for $\alpha = 2$ and for the fifteen-month period from June 2001 to August 2002. BPM values can range from 0 to 15, with a 15 indicating that in every month, the backorder-to-demand ratio $\hat{p}_{x,m}$ exceeded the threshold α.

B. THE WILCOXON RANK SUM TEST

When analyzing data that were randomly sampled from an unknown or non-normal probability distribution, statistical testing utilizing *t*, *F*, or any other procedure based on an assumption of normality can give misleading results (Devore, 2000). In the case of the F404 data, it was noted in Chapter III Section C that most of the 669 items had quarterly demands of zero, and that some of the remaining items exhibited high demands. Quarterly demand is, therefore, a case in which an assumption of normality cannot be reasonably made. The normal quantile-quantile (QQ) plots shown in Figures 4.1 and 4.2 demonstrate the non-normality of the quarterly demand data and the BPM values, respectively, based on the F404 engine data. The abundance of values at or near zero indicates decisively non-normal data.

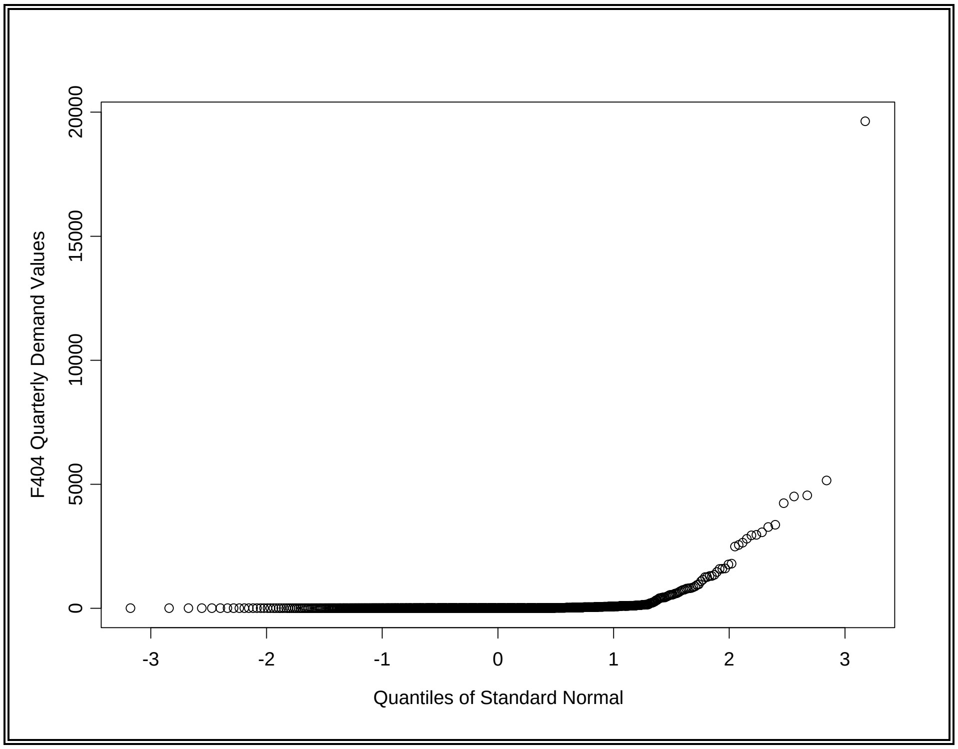

Figure 4.1: **Normal Quantile-Quantile Plot of the F404 Engine System Quarterly Demand Data.**

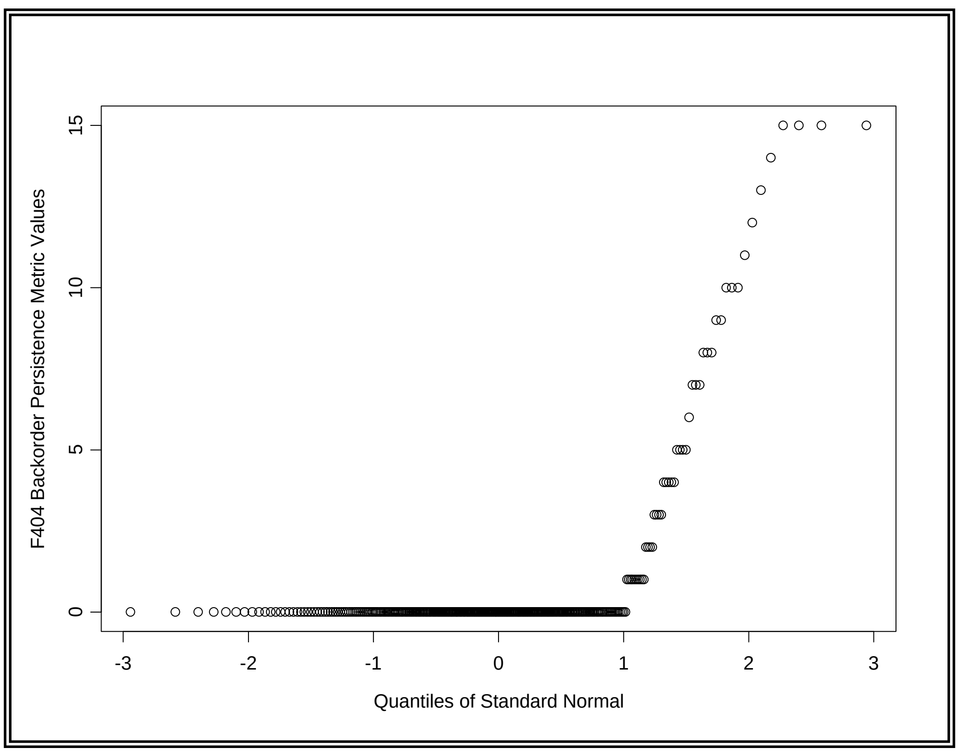

Figure 4.2: **Normal Quantile-Quantile Plot of the F404 Engine System BPM values.**

The focus of this analysis is to determine if there is any difference in BPM for F404-related items with a specified error type compared to the complementary set of F404 items. This requires separating the F404 data into two samples – items with a particular error and items without that particular error – and testing for differences in the locations of the BPM values of the two groups. The Wilcoxon Rank Sum Test (WRST), a nonparametric technique that is not based on an assumption of normality, was used to perform these evaluations.

The WRST is conducted as follows. Both samples (with and without a specific error type) are treated as a single ordered sample on the basis of BPM values, and ranks are assigned to each data point from smallest to largest. In the case of ties, averaged ranks are assigned. The WRST test statistic is then taken to be the sum of the ranks assigned to the smaller of the two samples. Comparison of the test statistic with critical values obtained from a statistical table, or from software such as S-Plus®, determines if the BPM values for items with the error type are significantly larger than for items lacking that same error.

Using ranks of the data values rather than the actual data has several advantages (Conover, 1999). BPM is arguably more useful as an ordinal value than as a numerical value; for example, it is difficult to justify treating a BPM value of 6 as "twice as bad" as a BPM value of 3. Second, the distribution of BPM is clearly not normal, as shown in Figure 4.2.

1. Hypothesis Testing

The hypothesis testing framework of the WSRT is explained in Conover (1999). This test is used to test the null hypothesis that the probability distributions of two populations are the same, against the alternative hypothesis that one distribution is "larger" than the other (one-tail test), or that the two distributions are not the same but nonetheless comparable as either "larger" or "smaller" (two-tail test). Because the aim of the thesis research was to analyze the influence of MDF data errors on backorders, the samples consist of F404-related items which, respectively, exhibit the error or do not exhibit the error.

2. Testing Assumptions

A fundamental assumption of the Wilcoxon Rank Sum Test is that the data comprise independent random samples from their respective populations (Conover, 1999). Although many line items experience multiple error types, as shown in Table 3.2, all comparisons are made within individual error types. Under the null hypothesis, it is assumed that it is reasonable to treat F404-related items that belong to the same error-criterion split as having BPM values assigned to them in a "random" manner.

C. RESULTS OF BPM TESTING

Setting the threshold parameter $\alpha = 2$, BPM calculations were made on the F404 backorder data. The outcomes were then applied to an error comparison function that split the data set by each error type. This effectively created the two samples required for WRST evaluation. Results of the tests are presented in Table 4.2 below. Due to the fact that BPM cannot be calculated for an item if the quarterly demand is zero, the number of line items evaluated reflects only those F404-related items exhibiting positive quarterly demand attributes.

Table 4.2 gives the results of Wilcoxon Rank Sum Tests for only the nine error types which had more than one item exhibiting the error. From the two-tailed p-values of these tests, it is seen that two of the error types, "AF" and "CO", produced statistically significant results at the $\alpha = .05$ level. Rejection of the null hypothesis is strongly indicated for the "AF" error type, for which the p-value is .0083. In the following two subsections these two tests are further explored.

Table 4.2: Wilcoxon Rank Sum Test Results based on BPM values

Error Type	Sample Size with Error	Mean BPM of Items with Error	Sample Size without Error	Mean BPM of Items without Error	WRST Z-value	WRST p-value
A	11	1.272	295	0.898	–1.7814	0.0749
AD	8	1.000	298	0.909	0.1646	0.8693
AE	12	0.250	294	0.939	0.7216	0.4706
AF	34	2.588	272	0.702	–2.6413	0.0083
AX	9	0.000	297	0.939	1.2861	0.1984
CB	3	0.000	303	0.923	0.8478	0.3966
CO	31	0.032	275	1.011	2.0257	0.0428
EB	19	0.000	287	0.972	1.9033	0.0570

The Sample size with and without error is a count of the items meeting the testing criteria. Mean BPM represents an unweighted arithmetic mean of all the BPM values for each respective sample. A Mean BPM of 0.000 is possible only when the items in the sample experienced no backorders during the evaluated period (June 2001 to August 2002). WRST Z-value and p-value are the statistical results of WRST evaluation, for two-tailed tests. Shading is applied to rows for which the p-values are smaller than 0.05. No correction is made for multiple testing.

1. Testing Results for Error Type "AF"

With a p-value of 0.0083, the "AF" error type shows a strong relationship to backorders. The mean BPM for the "AF" error is markedly larger than any of the other error types, which indicates a higher rate of backorders for items that exhibit this error type than for items without the error type. Table 4.3 presents a categorized breakdown of the BPM values for "AF" error items:

Table 4.3: Comparison of BPM Values for "AF" error items

BPM Range	0	1-3	4-6	7-9	10-12	13-15	Total
Count of AF Items	24	2	2	2	0	4	34
Count of Non-AF Items	235	16	8	6	4	2	271

Count of "AF" Items shows the number of F404 line items with BPM values in the range category from the first row. Non-"AF" Items refers to the F404 line items not affected by the "AF" error type.

It is interesting to note that, of the six items with BPM values in the 13 to 15 range, four items exhibited the "AF" error. Table 4.4 examines these four items in greater detail. It is seen that each of these is a repairable item having both high unit cost (replacement prices) and high quarterly demand. High BPM values for these items are therefore indicative of numerically large numbers of backorders.

Table 4.4: Attributes of Extreme BPM Value Items with "AF" Errors

NIIN	Item Name	Quarterly Demand	Replacement Price	Repairable Indicator	BPM
014456362	TRANSMITTER	60.00	5,467.45	Y	15
013140716	PUMP, FUEL	25.50	15,500.00	Y	13
011240903	ACTUATOR	51.50	11,765.75	Y	14
012374089	POWER UNIT	53.01	52,182.00	Y	15

As explained in Chapter II Section D.1, the "AF" error reflects a situation where manual intervention by NAVICP may be required to complete a requisition, as it needs to identify a qualified supplier for the restricted source item. However, it was not possible to ascertain whether this did indeed cause the backorder problem exhibited by the four items described in Table 4.4.

2. Testing Results for Error Type “CO”

While the “AF” error appears to induce large backorder quantities on items, the mean BPM value in Table 4.2 for the “CO” error seems to indicate the opposite effect. However, upon further investigation this was found not to be the case. The low mean BPM value from Table 4.2 can be attributed to the breakdown of the individual items’ BPM measurements, as 30 of the 31 items with a “CO” error have a BPM of zero and 1 item has a BPM greater than zero. Meanwhile, 229 items without a “CO” error have a BPM of zero and 46 items have a BPM greater than zero.

Testing a null hypothesis that the proportion of BPM values greater than zero to BPM values equal to zero is equal between those items without a “CO” error and those items with a “CO” error, a Chi-square test on the proportion fails to find any significant differences between the two groups with a p-value of .0761. Restated, based on the proportion of BPM values greater than zero to values equal to zero, there is not a true difference between the two samples. Given that the WRST results of the BPM were only marginally significant with a p-value of .0428, the lack of a substantial difference should not be disappointing.

Applying the same proportion test to the “AF” error samples rejects the null hypothesis with a p-value of .0147: the proportion of BPM values greater than zero on items with the “AF” error significantly differs compared to those items without an “AF” error. After refining the proportion test with an alternative hypothesis that BPM proportion of “AF” error items is actually greater than those without the error, the null hypothesis is more strongly refuted with a p-value of .0074.

D. RESULTS OF SMA TESTING

The analysis of the previous section was repeated using Supply Material Availability (SMA) as the inventory performance metric. Table 4.5 presents the results of this analysis.

Table 4.5: Wilcoxon Rank Sum Test Results based on Fiscal Year 2002 SMA values

Error Type	Sample Size with Error	Mean SMA of Items with Error	Sample Size without Error	Mean SMA of Items without Error	WRST Z-value	WRST p-value
A	11	0.7107	282	0.7346	–0.0798	0.9364
AD	8	0.7224	285	0.7341	0.2566	0.7975
AE	17	0.7871	276	0.7305	–0.9229	0.3560
AF	27	0.5779	266	0.7492	2.7664	0.0057
AX	10	0.7015	283	0.7348	0.2365	0.8131
CB	5	0.8000	288	0.7326	–0.8801	0.3788
CO	20	0.7250	273	0.7343	–0.7822	0.4341
EB	2	1.0000	291	0.7319	–1.2900	0.1970

The sample size with and without error is a count of the items meeting the testing criteria. Mean SMA represents an unweighted arithmetic mean of all the SMA values for each respective sample. WRST Z-value and p-value are the statistical results of WRST evaluation. Shading is applied to statistically significant p-values at the 0.05 test level.

It is seen that the "AF" error type is the only one that provides a significant split based on SMA. The 27 F404-related items with the "AF" error had an average SMA of about 58%, compared to an average SMA of 75% for the 266 items without the "AF" error. This finding is consistent with the analysis based on BPM, which found that presence of the "AF" error was associated with higher backorder rates. A comparison of SMA values based on the "AF" error is presented in Table 4.6**.**

Table 4.6: Comparison of SMA Values for "AF" error items

SMA Range	0.00 to 0.20	0.21 to 0.40	0.41 to 0.60	0.61 to 0.80	0.81 to 1.00	Total
Count of AF Items	**7**	**4**	**2**	**1**	**13**	**27**
Count of Non-AF Items	**41**	**13**	**22**	**21**	**169**	**266**

Count of "AF" Items shows the number of F404 line items with SMA values in the range category from the first row. Non-"AF" Items refers to the F404 line items not affected by the "AF" error type.

Review of the 11 items with the "AF" error and SMA less than 0.41 revealed a mixture of repairable and non-repairable items that included the four items with high BPM described in Table 4.4. The BPM values for these low-SMA items ranged from zero to fifteen, with a mean of 7.73 and a median of 9.0.

E. COMPARISON OF BPM AND SMA

SMA is a ratio of requisitions filled to requisitions received while BPM is the count of time units for which a backorder-to-demand threshold is exceeded. At a more fundamental level, both inventory performance metrics are based upon the accuracy of quarterly demand forecasts, which is an important element of the requirements determination process.

As a key Naval inventory performance metric, SMA is used in inventory policy making as a service level objective. A service level indicates the ability to meet customer demands from stock, reflecting the probability that a demand will be immediately filled. NAVICP has adopted a service level objective of 0.85 (Croll, 2003), but bases the ratio on satisfying requisitions from stock rather than individual demands. The stock service level drives inventory management decision-making to satisfy 85 percent of customer requisitions. It is also the prediction target for demand forecasts. The stock and delivery parameters are system objectives; however, for individual line items, calculated SMA based on actual requisitions may fall short of or exceed the stated goals. SMA serves as a performance measure for individual items while approximating a service level for the inventory system (Maher, 2003).

When a requisition cannot be filled from stock, a backorder is created to meet that requisition. The more requisitions that cannot be filled from stock, the greater the number of backorders. It follows that as SMA values fall, BPM values should increase. Figure 4.3 illustrates the inverse relationship between BPM and SMA. For the 249 F404-related items having both SMA and BPM values, a sample correlation coefficient of –0.609 was obtained.

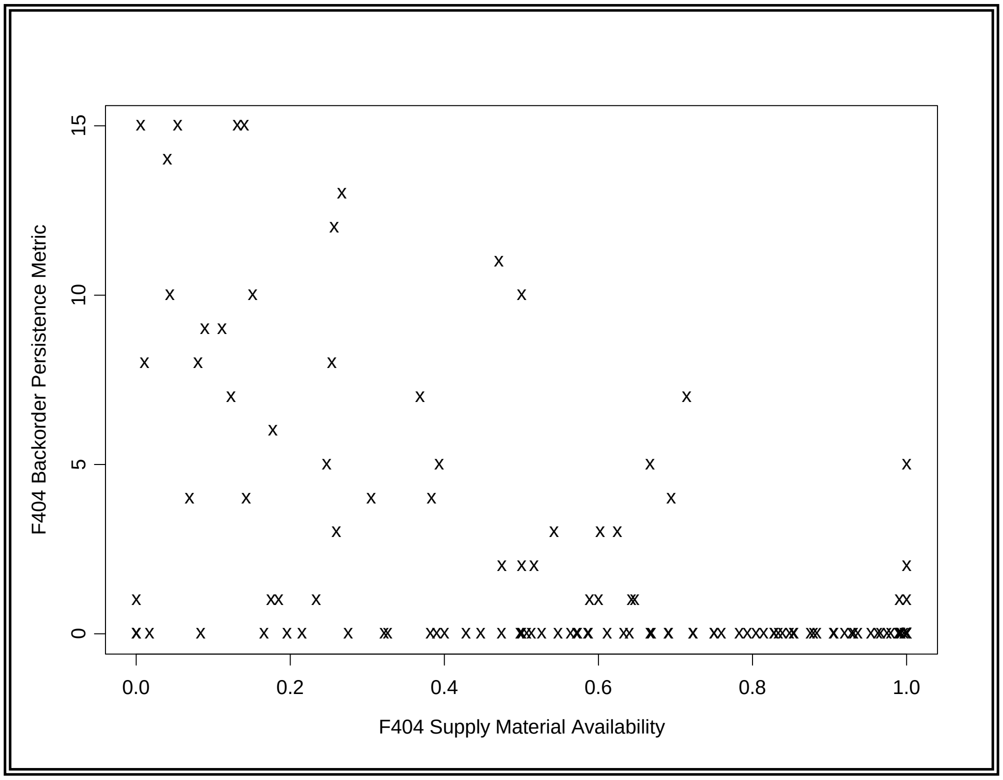

Figure 4.3: Comparison Plot of SMA and BPM for the 249 F404 Items Exhibiting Both Metrics

This result suggests that SMA and BPM both describe similar aspects of inventory performance, but in different ways. Preferably, both metrics can be used together to capitalize on the different types of information that are expressed through them.

F. ESTIMATING RETURN ON DATA-QUALITY INVESTMENT

Sections C and D present strong statistical evidence that the "AF" error is associated with inferior inventory performance, using either BPM or SMA as a performance metric. While SMA offers service level objectives that are useful in determining inventory system costs, backorder history and MDF data offer sufficient information to determine a specific cost for an item due to a persistent backorder condition. Associated with a given service level is an imputed or implicit stockout (backorder) cost (Tersine, 1998). By quantifying the difference between the current

backorders and the threshold level of backorders, the number of backorders in excess can be ascertained. It is this excess number that will provide the number of units that 1) should be reduced by correcting the "AF" error for each item, and 2) enables calculation for a return on data quality investments as imputed costs for excess backorders are eliminated. For backorder cost per unit (Tersine, 1998),

$$A = \frac{pFQ}{R\,P_{\text{Stockout}}},$$

where:

A	=	Backorder cost per unit
p	=	Unit price
F	=	Holding cost rate[3]
Q	=	Economic order quantity (EOQ)[4]
R	=	Annual demand
P_{Stockout}	=	Probability of a stockout ≈ (1 – Service Level)

The unit price, economic order quantity and annual demand (four times the quarterly demand) attributes are available from each item's MDF record. For illustrative purposes, the UICP Total Variable Cost holding cost rate of 0.23 will be utilized in calculations below (Maher, 2003). The objective stocking level (0.85) is subtracted from 1.0 to arrive at 0.15 as the probability of a backorder assuming the NAVICP SMA goal is met.

Once the backorder cost per unit has been determined, the issue of excess backorder quantities must be addressed. By computing an arithmetic mean of backorders for items identified with large BPM values, and then removing the portion of backorders

[3] Holding costs are those cost items involved with investing in inventory, incorporating capital costs, taxes, deterioration, et cetera. The holding cost rate is based on the assumption that holding cost is proportional to the size of the inventory investment, representing the system overhead expense level.

[4] A mathematically derived order size that minimizes the total inventory cost associated with an item.

considered reasonable—essentially, the "reasonable backorder portion" is the time-period adjusted demand value multiplied by the threshold parameter. In the present analysis, calculating the average monthly backorder quantity over the fifteen month time period from June 2001 to August 2002, and then subtracting two times the monthly demand value, reveals the excess backorder quantity. The product of the excess backorders quantity and the backorder unit cost represents the return on investment for removing the error of concern.

Table 4.7: Evaluation of Imputed Backorder Costs

NIIN	Unit Cost	Average Backorders	Excess Backorders	Excess Costs
014456362	$69.86	72.067	32.067	$2,240.24
013140716	$0.00	22.933	5.933	$0.00
011240903	$350.31	73.667	39.333	$13,778.75
012374089	$2,641.42	102.400	67.060	$177,133.66

Table 4.7 provides an example of imputed backorder cost calculations. The Average Backorder represents the mean monthly quantity. Excess Backorders was calculated by subtracting two times the monthly demand. A backorder cost of $0.00 is possible if the item EOQ is zero.

From Table 4.7, the costs associated with the excess backorder quantities on the four items with extreme BPM values presented in Table 4.4 are provided. On just these four items, the expected reduction in backorders by correcting their "AF" error conditions could yield over $193,000 in savings based on backorder reductions in a one-month period. Any realized savings would not be apparent until completion of the first post-error correction procurement cycle.

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V. SUMMARY AND CONCLUSIONS

The central issue of the research described in this thesis is the prioritization of error correction efforts in NAVICP data files. Focusing on Master Data File (MDF) records for items in the F404 engine group, two metrics – Backorder Persistence Metric (BPM) and Supply Material Availability (SMA) – were used to evaluate relationships between data errors and backorders through application of the Wilcoxon Rank Sum Test. Both BPM and SMA measurements indicated the existence of a relationship between a specific error type and reduced inventory performance.

The identification of known data errors that adversely affect inventory management operations can be addressed with the use of BPM. Through the evaluation of backorder quantities on items in the F404 engine data utilizing BPM, it was determined that one of the MDF error types, assigned the code "AF" by NAVICP data quality activities, exhibits a statistically significant association with excessive backorder quantities for F404-related items. Potential savings in inventory-system costs associated with reducing excess backorder quantities for four F404-related items that exhibited this error was estimated to be over $193,000 in savings based on backorder reductions in a one-month period. Any realized savings would not be apparent until completion of the first post-error correction procurement cycle.

A BPM-based analysis allows NAVICP to set a user-defined threshold for excessive backorders. This allows inventory managers and data quality specialists to select criteria that are consistent with inventory management objectives. BPM analysis can also be applied to any set of inventory items provided that the requisite information is available.

Statistical testing using SMA also provides insight into the relationship between MDF data errors and the availability of inventory material. It was found that the "AF" error type exhibits a statistically significant relationship with low SMA values, which is consistent with the result of testing using BPM. As expected, there was a moderate negative correlation between BPM and SMA over the F404-related items considered in the research.

In light of these finding, the following three recommendations are made to improve the data quality enhancement effort at NAVICP:

1. Top priority should be given to the correction of major database errors that are strongly related to high BPM or low SMA. One such error in particular, the one assigned the code “AF” by NAVICP, should be given a high priority for remediation.

2. In addition to the use of SMA, adopt BPM as a metric for inventory performance with respect to data quality improvement activities at NAVICP.

3. Adopt shortage-cost avoidance as a criterion for prioritization of data-quality remediation efforts.

The following areas offer opportunities for future research that extend the work described in this thesis:

1. Enhance BPM analysis to include items with zero demand, thereby expanding the scope of this inventory performance metric. Assimilating the entire population of items with backorders may reveal additional associations between data errors and affected items.

2. Fine-tune the methodology for determining the return on investment in data quality associated with the reduction of backorders in terms of operational availability or obviated shortage costs.

APPENDIX A: ADDITIONAL INFORMATION ON MASTER DATA FILE ERRORS

Tables in this appendix provide amplifying information on MDF data errors, particularly the three error types discussed in Chapter II Section D.

- Table A.1 lists the auditing rules for the "AF", "CB" and "CO" error types as applied to the August 2002 data quality audit at NAVICP.
- Table A.2 details the database attributes evaluated in the course of the monthly error audit for the "AF", "CB" and "CO" error types.
- Table A.3 shows summary output from the MDF error audit of September 2002. All MDF error types that affected items related to the F404 engine are listed.

Table A.1: Diagnostic Audit Rules for the Three Most Common Error Types in the F404 Engine Data as of August 2002.
Italicized comments added by author.

(From: Alcorn, 2002)

Error Code	**Criteria**	
	AND statements listed vertically	**OR statements**
AF	E089 is not equal to 'V' or 'Y'	
	D025F is equal to 'B'	
	A Reference Number Trailer (D001) *exists* where C038 is equal to 'P'	
	D024 is not equal to '1'	Position 2 of D027 is not equal to 'K'
CO	C042 is not equal to Non-IMC Classes	
	D120 is not equal to '8D'	
	D025F is equal to 'B' or 'C'	
	C016 is not equal to 'E', 'D', or 'J'	
CB	B067E is equal to 'Y'	
	No Alternate NIIN (D016) *listed*	
	An Application (D009) *exists* where (D029 is equal to its volatile den parameter	
	F018 is not equal to '100'	

The Criteria column expresses the DEN field name under evaluation and the audit rule applied to that field. The vertical listing of criteria indicates "AND" checks while the horizontal location of an audit rule indicates an "OR" check. For example, CB evaluates four criteria, finding a disagreement between the data underlying criterion 1 AND criterion 2 AND criterion 3 AND criterion 4.

Table A.2: Master Data File Data Element Numbers (DEN) Descriptions for the "AF", "CO" and "CB" Error Types.

Error Code	DEN Label	Definition	Values
AF	E089	**Acquisition Advice Code** A Code denoting how, as distinguished from where, and under what restrictions an item will be acquired.	Single alphabetical character indicating ownership and disposition of material, A through Z.
	D025F	**Acquisition Method Suffix Code** A code that indicates the reason a particular procurement method, identified by the assigned Acquisition Method Code (DEN D025E), has been selected.	Single digit alpha-numeric code, 0 and A through Z, with the possibility of invalid combinations.
	D001	**Reference Number** Any number, other than an activity stock number, used to identify an item of production; or to identify an item of supply. Includes manufacturers' or Government part, drawing, model, type and source controlling numbers; and specifications or standard part, drawing, or type numbers. Must be accompanied by its applicable Commercial and Government Entity (DEN C035).	No established format
	C038	**Procurement Number Code** Identifies the reference number(s) within an item record which will be utilized in procurement.	P: Reference Number to be used for procurement. R: Reference Number to be used for procurement from the authorized additional manufacturing sources indicated in C035B. X: Reference Number not to be used for procurement.
	D024	**Reference Number Category Code** Designates the relationship of a reference number (D001) to the item of supply.	Single digit alphanumeric value.
	D027	**Type of Number Code** Indicates the type of number represented by the reference number (drawing number, part number, specification number, etc).	Two digit numeric plus alphabetical character combination, based upon DEN D024 data.

Error Code	DEN Label	Definition	Values
CO	**C042**	**Federal Supply Classification** The first two digits of C042 identify the commodity group; the last two identify the class within group.	Refer to DOD 4100.39M for valid Federal Supply Classes.
	D120	**Level of Authority** Identifies the levels authorization of a Primary Inventory Control Activity and/or a Secondary Inventory Control Activity. Indicates (1) Logistics Material Management, (2) Level of Responsibility, and (3) Basis of Categorization.	Two digit alphanumeric code associated with an organizational level of control.
	D025F	**Acquisition Method Suffix Code** A code that indicates the reason a particular procurement method, identified by the assigned Acquisition Method Code (DEN D025E), has been selected.	Single digit alphanumeric code, 0 and A through Z, with the possibility of invalid combinations.
	C016	**Item Management Code** Indicates whether an item shall be subject to integrated management, or shall be retrained by the individual military services, or other DOD component, for their management. IMC code assignment is required for all National Stock Numbered items assigned a Federal Stock Class (C042) designated for Integrated Material Management.	Single alphabetical character designating the nature of repair or maintenance ownership.
CB	**B067**	**Program Related Future Demand** Indicates whether an item is program related for future demand.	Y or N Coded N for all repairable SE End Items except (1) where an item is common to an avionics system and a SE End Item . . . Consequently, the avionics application takes precedence and B067E = Y.
	D016	**Alternate NIIN** A NIIN referenced in an item record that may be used in lieu of the record item. Always accompanied by the alternate NIIN relationship code (D016A), provides information concerning the preference and degree of interchangeability.	Nine digit numeric code for National Item Identification Number.

Error Code	DEN Label	Definition	Values
	D009	**Application Code** Identifies the next higher-level assembly/ weapon (e.g. Aircraft, Engine Repairable Assembly or System) within which the item of record is contained or to which it is related. Additionally utilized to designate applicability to special management programs and projects and to identify miscellaneous data.	None offered.
	D029	**Application/Identification Number Activity Code (AINAC)** Specifies the nature or type of Model Code RIC (Repairable Identification Code), DEN D008, or application code, DEN D009. Once a D029 is established for a Model Code/RIC, that specific D029 must always be used in conjunction with that Model Code, when used as an application (D009), or as a Level C Header in the WSF.	Two character alphabetical code. Level C AINACs have a second character of P through Z.
	F018	**Percent Per Application** A numerical figure expressing the percentage of a specific application for which an item is required for support.	Repairable Items Value for a specific application of any item shall not exceed 100. Percent Application shall be determined after due consideration of installations and spares (all condition codes and on order).

The DENs are indexed by Error Code and listed by DEN label, definition and value associations. The label indicates the position of the field within the item's record. The Definition column provides the name attribute of the DEN field with the meaning provided underneath. The Values column details the form of the data within the DEN field.

Table A.3: MDF Diagnostic Output Summary from September 2002

(From: Alcorn, 2002)

MDF ERROR CODE	ERROR COUNT	NUMBER OF RECORDS EXAMINED 9/3/2002	QUALIFICATIONS FOR TESTING RECORDS
AA	0	161,279	ALL MDF NIINS
AC	289	288,640	ALL D001'S WHERE C003 NE 6V**LOGIC CHG 8/22/02
AD	8,010	225,234	ALL D001'S WHERE E089 NE V,Y
AE	4,721	63,407	ALL D001'S WHERE E089 =V,Y**LOGIC CHG 8/27/02
AF	9,035	225,234	ALL D001'S WHERE E089 NE V,Y
AJ	225	161,279	ALL MDF NIINS
AL	7	161,279	ALL MDF NIINS
AM	1,026	8,794	D025D=3,E
AN	88	161,279	ALL MDF NIINS
AO	212	161,279	ALL MDF NIINS
AP	405	189,988	ALL D009'S WHE D013B=B,Z & D013C=A,Z
AQ	319	81,801	D013C NE D or K
AR	2,403	81,255	ALL D009'S WHE D013B=F,G,H,L,O D013C=F,G,H,L,O
AS	134	161,279	ALL MDF NIINS
AT	16	161,279	ALL MDF NIINS
AU	234	79,685	C003A=E,H,X
AV	86	12,061	C003A=D
AW	162	44,397	C003A=M
AX	3,607	609,117	ALL D009'S
AY	223	7,711	C003=6R
BA	940	7,711	C003=6R
BG	413	657	ALL F016'S WHERE D012A=J(1NIIN CAN HAVE MANY F016'S)
BI	309	161,279	ALL MDF NIINS
BJ	83	161,279	ALL MDF NIINS
BM	23	161,279	ALL MDF NIINS
BN	9	161,279	ALL MDF NIINS
BT	260	161,279	ALL MDF NIINS
BX	5,589	568,405	ALL D009'S WHERE C003B NE B4
BY	479	609,117	ALL D009'S
BZ	2,539	524,466	ALL D009'S WHERE D012 NE PB,PD,PE
CB	3,730	29,214	B067E=Y
CC	1,481	524,466	ALL D009'S WHERE D012 NE PB,PD,PE
CG	1,827	14,573	ALL D009'S WHERE D012=PB

MDF ERROR CODE	ERROR COUNT	NUMBER OF RECORDS EXAMINED 9/3/2002	QUALIFICATIONS FOR TESTING RECORDS
CJ	431	24,634	C003A=W/X
CK	9,458	161,279	C003A=E,G,H,Q,X
CN	24	161,279	ALL MDF NIINS
CO	5,929	161,279	ALL MDF NIINS
CP	4,885	161,279	ALL MDF NIINS
CQ	4	161,279	ALL MDF NIINS
CT	2	161,279	ALL MDF NIINS
CU	14,227	161,279	ALL MDF NIINS
CV	178	29,214	B067E=Y
CX	978	6,401	ALL CNS NIINS
DA	257	1,695	C129M>OR=1000 (new logic 8/26/02)
DB	43	161,279	ALL MDF NIINS**NEW LOGIC 8/26/02
DC	12	49,350	C003=1R**NEW LOGIC 8/26/02
DL	26	161,279	ALL MDF NIINS
DM	895	92,784	C003 NE 7R
DN	419	161,279	ALL MDF NIINS
DQ	1,286	161,279	ALL MDF NIINS
DR	726	84,223	D120=8D,22
DT	69	68,234	D120=22
DW	699	63,119	D093=N1R5
DX	1,956	68,171	D093=N2R4
DY	1	5	D093=N2R2
EA	36	4,231	D012=PB (new addition 1/1/02)
EB	3,297	161,279	ALL MDF NIINS

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APPENDIX B: DESCRIPTION OF INVENTORY ITEM DATA

The tables presented in this appendix are extracts (except where noted) of the data files provided by NAVICP for this research, presented here to familiarize the reader with the form of the inputs required for BPM analysis. Only the first twenty-five records from the F404 Basic-Item Descriptive Data file and Backorder History file are listed to provide a (non-inclusive) sense of the range exhibited by the data values. For continuity, the same items are reproduced in each of these two tables. One hundred of the 483 records in the Error Incidence file are offered for review.

- Table B.1 is the F404 engine attributes file used in the analysis.
- Table B.2 is the Backorder History file, with data from June 2001 to August 2002.
- Table B.3 is the Error Incidence file, with data from the August 2002 error audit.
- Table B.4 lists the records from the Basic-Item Descriptive File that are affected by the "AF" error type.

Table B.1: Sample Records from the F404 Basic-Item Descriptive Data File

Item Number	Item Name	Quarterly Demand	Item Price	REP	SMA	BPM	EOQ
012364368	WASHER,FLAT	0	0.92	N	NA	NA	1
012582503	LINER,AFTERBURNER	0	29473	Y	NA	NA	0
012612720	SEGMENT,WIGGLE STRU	0	1.99	N	1.000	NA	1
012908912	LINER,AFTERBURNER	0	29473	Y	NA	NA	0
012911177	SEAL,ROD	0	67	N	NA	NA	1
012911179	RIVET,SPECIAL	0	3.22	N	1.000	NA	2
012917066	NUT,SELF-LOCKING,EX	0	2.93	N	1.000	NA	0
012965754	LINER,AFTERBURNER	39	21950	Y	0.150	10	40
013230847	DOUBLER, FLAP	0	148.02	N	NA	NA	1
013416044	ACTUATOR,HYDRAULIC-	63	6000	Y	0.996	0	5
013922782	TAB,VEN	15	10	N	1.000	0	90
013970512	RING,VEN ACTUATING	36	19883.20	Y	0.633	0	2
014371154	BEARING,SLEEVE	39.89	12.99	N	0.500	0	NA
014382711	FLAMEHOLDER,AFTERBU	0	16002.56	N	NA	NA	0
014456362	TRANSMITTER,POSITIO	60	5467.45	Y	0.131	15	2
014470611	KIT,OVERHAUL	0	492.66	N	NA	NA	NA
014503755	FLAMEHOLDER,AFTERBU	195.90	16002.56	N	0.936	0	354
014569869	SCRAPER,ROD,TRANSMI	0.99	15.99	N	0.500	10	6
014569872	CAPSTRIP,TRANSMITTE	0.79	5.12	N	0.714	7	2
014569875	PACKING,PREFORMED	1	88.10	N	1.000	5	5
014569877	PACKING,PREFORMED	1.59	72.81	N	1.000	0	5
014574157	PACKING,PREFORMED	6.59	35.06	N	0.875	0	69
011302765	SHROUD,STATOR	0	787.25	N	NA	NA	0
011302768	NOZZLE SEGMENT	935.76	695	N	0.498	0	0
011302769	NOZZLE SEGMENT	18	695	N	1.000	0	0

Item Number corresponds to the NIIN (DEN D046D). The quarterly demand is the forecasted demand during procurement lead-time (DEN B074). Item Price is the replacement price (DEN B055). REP indicates the repairable status of an item. SMA and BPM are calculated values from NAVICP and this research, respectively. BPM for an item with forecast demand of 0 is “NA”. EOQ is the economic order quantity, the re-order quantity for an item computed by NAVICP (DEN B021).

Table B.2: Sample Records from the F404 Backorder History File

	Date (Month and Year)														
Item Number	**06-01**	**07-01**	**08-01**	**09-01**	**10-01**	**11-01**	**12-01**	**01-02**	**02-02**	**03-02**	**04-02**	**05-02**	**06-02**	**07-02**	**08-02**
012364368	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012582503	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012612720	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012908912	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012911177	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012911179	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012917066	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012965754	8.00	6.00	16.00	25.00	27.00	36.00	36.00	32.00	26.00	27.00	35.00	41.00	47.00	46.00	55.00
013230847	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
013416044	1.00	2.00	2.00	0.00	0.00	0.00	1.00	3.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
013922782	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
013970512	0.00	0.00	0.00	0.00	1.00	1.00	0.00	4.00	3.00	3.00	13.00	17.00	14.00	11.00	9.00
014371154	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
014382711	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
014456362	53.00	53.00	53.00	78.00	80.00	107.00	94.00	65.00	57.00	60.00	82.00	85.00	76.00	66.00	72.00
014470611	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
014503755	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	15.00	1.00	6.00	10.00	5.00	5.00	0.00
014569869	2.00	2.00	2.00	5.00	5.00	6.00	7.00	9.00	5.00	4.00	0.00	0.00	0.00	0.00	0.00
014569872	3.00	3.00	3.00	4.00	5.00	5.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
014569875	1.00	1.00	2.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
014569877	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
014574157	2.00	2.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
011302765	0.00	0.00	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
011302768	9.00	6.00	7.00	9.00	0.00	22.00	22.00	23.00	22.00	23.00	19.00	42.00	44.00	68.00	67.00
011302769	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Backorder quantities on record by month are listed from June 2001 to August 2002.

Table B.3: Sample Records from the F404 Error Incidence File

Item Number	Error Code	Item Number	Error Code	Item Number	Error Code	Item Number	Error Code
012364368	AE	012917066	AF	013330320	AE	013952748	AX
012374089	AF	012917066	CO	013416044	AF	013952748	AX
012374089	AF	012917066	EB	013416044	AF	013952748	AX
012374089	AF	012936265	EB	013416044	AF	013959278	CB
012513853	AE	012936265	CO	013438946	AE	013968508	AD
012547280	AE	012936266	CO	013438946	CO	013972495	AF
012565486	DA	012936266	EB	013474408	DX	013972495	AF
012570996	EB	013001623	AE	013535862	AE	013978058	AE
012570996	CO	013001625	AE	013535863	CB	013978058	CB
012597134	AF	013036472	CO	013535863	CB	013986494	AX
012597134	AF	013136429	CO	013581114	AX	013986494	AX
012597134	AF	013136429	AE	013581114	AX	014177389	AD
012612720	CB	013136429	EB	013785438	CB	014292598	CO
012612720	CB	013140716	AF	013785438	CO	014292598	AF
012612720	CB	013140716	AF	013785438	AD	014371154	CO
012723733	AE	013140716	AF	013788486	AF	014434303	AF
012879017	AX	013171624	CB	013788486	AF	014434303	AF
012879017	AX	013188994	AF	013788486	AF	014434303	AF
012879017	AX	013188994	AF	013788486	AF	014435733	CB
012879017	AX	013188994	AF	013876724	AE	014435733	AD
012879017	AX	013188994	AF	013878443	CB	014435736	CB
012896322	AD	013229010	AE	013893543	CB	014435937	CO
012914289	AE	013230847	CO	013949255	AX	014436000	CO
012915037	CO	013230847	AE	013949255	AX	014436000	CP
012917066	AD	013330320	CO	013950930	AE	014456362	AF

Error Codes are listed with the item in which it was discovered during the August 2002 audit. The errors are aggregated by item (NIIN), and may reflect multiple instances of the same item. This can be attributed to the existence of multiple part numbers (assigned by commercial suppliers) that MDF tracks with separate records referring to the same NIIN. This issue has no impact on BPM analysis, which counts the number of NIINs affected by an error and not the number of the same error observed on the NIIN.

Table B.4: F404 Items Affected by the "AF" Error

Item Number	Item Name	Quarterly Demand	Item Price	REP	SMA	BPM	EOQ
011443921	NUT,SELF-LOCKING,HE	19625.98	4.83	N	1.000	0	39252
014984839	O-RING,AIRCRAFT EQU	0.01	0.12	N	NA	0	1
011240912	CABLE ASSEMBLY,THER	126	2090	Y	0.624	3	252
011293816	VALVE,FUEL PRESSURI	27.61	861.60	N	0	0	NA
011575485	NUT,SELF-LOCKING,EX	432	2.85	N	NA	0	1758
011684631	STUD,LOCKED IN	0.64	10.44	N	NA	0	4
011684632	STUD,LOCKED IN	14.25	35.97	N	NA	0	86
013416044	ACTUATOR,HYDRAULIC-	63	6000	Y	0.996	0	5
014456362	TRANSMITTER,POSITIO	60	5467.45	Y	0.131	15	2
014764190	SEAL,AIR,AIRCRAFT G	104	278.76	N	0.017	0	79
011560734	STUD,LOCKED IN	134	9.82	N	1.000	0	527
011560737	STUD,LOCKED IN	5.49	7.62	N	NA	0	33
011560738	STUD,LOCKED IN	68.75	7.62	N	NA	0	412
011594528	STUD,LOCKED IN	29.01	7.62	N	NA	0	174
012597134	FUEL FLOW TRANSMITT	28.5	3569	Y	0.089	9	7
013188994	COOLER,LUBRICATING	15	4995	Y	0.587	0	1
013788486	BEARING,BALL,ANNULA	146.01	1875	N	0.979	0	292
014292598	NUT,SELF-LOCKING	0.18	92.24	N	NA	0	NA
011397307	PUMP,FUEL,JET ENGIN	21.33	29182.72	Y	0.804	0	2
012155658	TRANSMITTER,COMPRES	19.32	9825	Y	0.853	0	4
013140716	PUMP,FUEL,METERING	25.5	15500	Y	0.267	13	0
011240903	ACTUATOR ASSEMLBY	51.5	11765.75	Y	0.040	14	4
011318620	NUT,SELF-LOCKING,SP	26.75	3.95	N	1.000	0	161
011542949	IGNITER,SPARK,GAS T	968.5	205	N	1.000	0	1937
011717568	DETECTOR,METALLIC P	41.07	270	N	1.000	0	79
012093043	PUMP,ROTARY	33	9633	Y	0.305	4	5
012185553	VALVE,ANTI-ICING	99.30	9250	Y	0.839	0	3
012374089	POWER UNIT ASSEMBLY	53.01	52182	Y	0.140	15	7
013972495	WINDING,GENERATOR F	74.01	3415	N	0.919	0	0
014621606	POWER LEVER CONTROL	132.30	23560	Y	0.233	1	8
014434303	CONTROL ASSEMBLY,PU	19	55000	Y	0.447	0	1
014574156	RELAY,ELECTROMAGNET	1.26	67.24	N	0.111	9	345
014574159	RELAY,ELECTROMAGNET	34.02	1163	N	0.974	0	34
014865747	FUEL CONTROL,MAIN,T	40.75	87019.98	Y	0.247	5	1

Item Number corresponds to the NIIN (DEN D046D). The quarterly demand is the forecasted demand during procurement lead-time (DEN B074). Item Price is the replacement price (DEN B055). REP indicates the repairable status of an item. SMA and BPM are calculated values from NAVICP and this research, respectively. An item with no calculated SMA will reflect "NA" as not available. BPM for an item with forecast demand of 0 is "NA". EOQ is the economic order quantity, the re-order quantity for an item computed by NAVICP (DEN B021).

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APPENDIX C: SOFTWARE USE FOR ANALYSIS

The following S-Plus® functions were used in performing the BPM analysis.

1. BPM Computation

The S-Plus® function reproduced below was used for the calculation of BPM values. Using the labels detailed below, "F404a" is the descriptive data file, formatted as indicated in Table B.1. Next, "Yback" is the Backorder History file. The last input, "alpha" is the backorder-to-demand threshold parameter, adjustable as desired by the user. The function returns a vector indicating the number of months the ratio of backorders to adjusted demand exceeds the threshold.

```
function(F404a, Yback, alpha)
{
# F404a contains demand and unit price data
# Yback contains backorders data
# alpha is a threshold number.
#
# Returns a vector of length = number of rows of F404a containing
# the number of months that the ratio of backorders to monthly
# demand exceeds alpha
#
# RAK 12-18-02
#
      nc <- dim(Yback)[2]
      YY <- as.matrix(Yback[, 3:nc])
      n <- dim(F404a)[1]
      ypers <- rep(NA, n)
      tmatch <- match(F404a[, 1], Yback[, 1])
      kk <- which(!is.na(tmatch) & F404a[, 4] > 0)
      m <- length(kk)
      for(j in 1:m) {
            kkj <- kk[j]
            i <- tmatch[kkj]
            ypers[kkj] <- sum((3 * YY[i,  ])/F404a[kkj, 4] > alpha)
      }
      return(ypers)
}
```

2. Error Comparison

The S-Plus® function reproduced below was used to segregate the F404 data into samples with and without each error type. Using the labels detailed below, "F404b" is the descriptive data file, formatted as indicated in Table B.1. Next, "ypers" is the vector containing the values for measurement of mean and subsequent comparison in the samples provided to the Wilcoxon Rank Sum Test. The last input, "EElist" is Error Incidence data file, formatted as indicated in Table B.3. The function returns a report indicating the error type, the number of items and the arithmetic mean of the metric of those items with the error, the number of items and the arithmetic mean of the metric of those items without the error.

```
function(F404b, ypers, EElist)
{
      tmatch <- match(EElist[, 1], F404b[, 1])
      tt <- !is.na(tmatch)
      elist <- sort(unique(EElist[tt, 2]))
      nerr <- length(elist)
      Y <- data.frame(elist, matrix(0, nerr, 4))
      names(Y) <- c("Error", "N.with", "mean.with", "N.without",
            "mean.without")
      for(j in 1:nerr) {
            tt <- EElist[, 2] == elist[j]
            tmatch <- match(F404b[, 1], EElist[tt, 1])
            tt <- !is.na(tmatch)
            if(any(tt)) {
                  Y[j, 2] <- sum(tt & !is.na(ypers))
                  Y[j, 3] <- mean(ypers[tt], na.rm = T)
            }
            if(any(!tt)) {
                  Y[j, 4] <- sum(!tt & !is.na(ypers))
                  Y[j, 5] <- mean(ypers[!tt], na.rm = T)
            }
      }
      return(Y)
}
```

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